A "STORMY" SORTIE FOR PRISTINE ROCKS IN LUNAR SOILS: 2. TRACE-ELEMENT COMPOSITIONS OF COARSE-GRAINED "HIGHLANDS" ROCKS FROM APOLLO 12.

G.A. Snyder, C.R. Neal*, J. Jain*, and L.A Taylor, Planetary Geosciences Institute, Univ. of Tennessee, Knoxville, TN 37996-1410 (gasnyder@utk.edu); *Dept. of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556

We have analyzed the trace-element compositions of twenty-six >1 mm igneous fragments from Apollo 12 soil 12001. Of these 26 fragments, 10 have been determined to be coarse-grained, presumably highlands rocks [1] and are presented here. Many of these rocks appear to be more slowly cooled versions of mare basalts, possibly from within thick basaltic flows on the Moon. However, true highlands cumulates do exist and we have identified one rare peridotite, three primitive gabbros, and a relatively primitive ferrogabbro from among these samples.

INTRODUCTION -- In order to study the distribution of highlands igneous components in the lunar regolith, and thus, to understand the petrologic and chemical character of the lunar upper crust, we have analyzed coarse-grained, presumably highlands-plutonic rocks from the eastern nearside of the Moon. In July of 1993, we began this study of 1-4 mm igneous fragments in Apollo 11 and Apollo 12 soils [1-4] that is completed with this report and a companion report on the Apollo 11 samples [5]. In total, we have analyzed over 64 igneous rock fragments for both mineral-chemical and bulk-rock minor element compositions.

TRACE-ELEMENT COMPOSITIONS OF IGNEOUS FRAGMENTS -- All ten rocks were analyzed for a suite of minor elements by ICP-MS at the University of Notre Dame (Table 1). The chondrite-normalized REE patterns for these samples are presented in Figs.1 & 2.

The trace-element characteristics of sample **,782** are consistent with the petrograhic and mineral-chemical classification of this sample as a **peridotite** [1]. This rock has the lowest Eu (0.31 ppm), Sr (35.0 ppm), Ba (16.2 ppm), Nb (1.0 ppm), and Ta (0.017 ppm) abundances (Table 1), and deepest negative Eu anomaly among the four lowest REE abundance samples (Fig. 1; filled square), indicative of its small proportion of plagioclase (<10 modal%) and oxides [1]. Peridotite **,782** also has among the highest abundance of Cr (6664 ppm) and Ni (169 ppm) (Table 1). This particular sample needs further study to distinguish whether it is a true peridotite from the lunar interior or a plagioclase-poor segre-

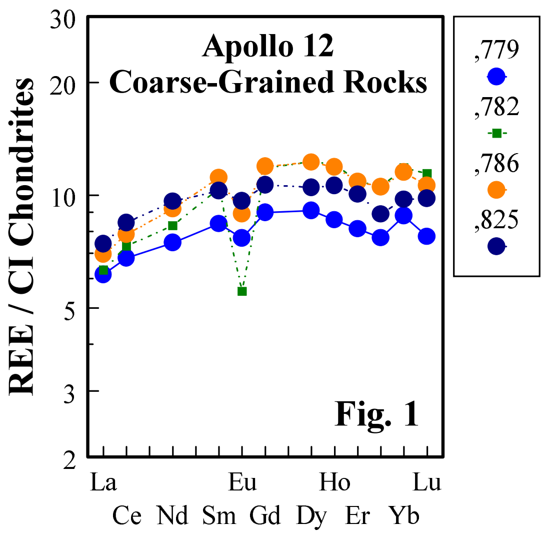
Table 1: Chemistry (in ppm) of 1-4 mm , Coarse-grained Rocks from Soil 12001

PM	**,779**	**,780**	**,782**	**,784**	**,786**	**,788**	**,789**	**,825**	**,798**	**,841**	**%error**
SS	,753	,754	,756	,758	,760	,762	,763	,762	,772	,767	
Rock*	GAB	MR	PER	IB	GAB	PB	PB	GAB	MR	FG	
Li	5.19	5.29	6.19	6.70	6.37	7.05	7.40	5.96	9.63	9.96	4
Be	0.16	0.88	0.31	0.79	0.29	0.52	0.53	0.17	0.92	1.26	10
Sc	31.6	35.8	46.0	47.9	39.3	38.1	43.5	32.0	55.3	83.9	15
V	149.8	93.8	230.8	83.4	243.0	167.4	153.8	188.1	155.8	264.2	8
Rb	0.28	1.34	0.49	1.02	0.26	1.02	0.97	0.14	1.61	2.90	11
Sr	62.4	95.3	35.0	83.0	65.4	83.6	105.6	75.3	128.1	220.8	4
Y	13.7	54.7	19.6	55.4	18.9	32.3	29.7	15.8	53.5	79.7	3
Zr	32.3	154.7	47.9	141.6	38.9	96.0	96.7	39.7	150.2	240.1	3
Nb	1.6	8.1	1.0	6.7	2.1	6.4	6.7	2.3	7.3	15.8	3
Ba	16.6	88.5	16.2	68.2	18.5	57.8	49.3	21.1	91.5	187.4	3
La	1.45	8.37	1.49	6.86	1.64	5.32	4.19	1.75	8.30	17.2	4
Ce	4.19	23.6	4.51	20.3	4.84	14.7	11.9	5.20	22.8	48.3	3
Pr	0.58	3.41	0.70	3.08	0.71	2.06	1.71	0.758	3.20	6.93	4
Nd	3.41	18.4	3.79	16.6	4.20	10.9	8.8	4.40	16.8	36.1	4
Sm	1.25	6.38	1.55	6.13	1.66	3.60	3.03	1.53	5.72	11.7	5
Eu	0.43	1.01	0.31	1.00	0.50	0.75	0.84	0.54	1.13	2.49	5
Gd	1.77	8.21	2.33	8.21	2.35	4.74	4.20	2.10	7.30	15.4	6
Tb	0.32	1.53	0.46	1.60	0.46	0.89	0.81	0.40	1.37	2.86	6
Dy	2.23	9.30	3.01	9.69	3.00	5.69	5.06	2.57	8.59	17.9	4
Ho	0.47	1.97	0.66	2.07	0.65	1.20	1.07	0.58	1.80	3.90	5
Er	1.30	5.13	1.75	5.58	1.74	3.52	3.14	1.61	4.84	11.0	5
Tm	0.19	0.74	0.26	0.86	0.26	0.47	0.42	0.22	0.69	1.52	6
Yb	1.40	4.82	1.88	5.70	1.83	3.18	2.97	1.55	4.69	9.86	6
Lu	0.19	0.70	0.28	0.84	0.26	0.45	0.42	0.24	0.70	1.45	8
Hf	1.17	4.57	1.38	5.04	1.35	2.79	2.72	1.17	4.06	8.30	8
Ta	0.089	0.40	0.017	0.34	0.11	0.38	0.38	0.15	0.31	1.17	10
Pb	0.29	0.89	0.16	0.31	0.40	1.19	1.09	0.14	0.46	1.76	20
Th	0.18	1.04	0.19	0.76	0.19	0.63	0.49	0.20	1.11	2.05	15
U	0.023	0.32	0.046	0.20	0.045	0.17	0.12	0.030	0.31	0.61	20
Ti (mg)	7.083	18.50	9.888	23.00	11.93	10.11	17.51	9.167	18.26	31.17	15
Cr	4383	3649	6664	2614	7440	3389	3671	4625	2988	4707	15
Co	70.9	67.7	68.7	38.0	73.8	49.7	61.3	70.3	39.9	70.2	3
Ni	82.4	96.4	169	39.2	66.7	79.9	105	137	23.4	31.5	4
Cu	11.3	16.8	26.3	13.9	9.10	11.7	32.7	9.40	15.1	36.5	4
Zn	10.2	15.3	17.1	12.2	11.2	15.4	27.1	11.3	21.4	35.6	6
Ga	1.63	1.79	1.62	1.71	2.10	1.85	2.20	1.94	2.96	21.5	4

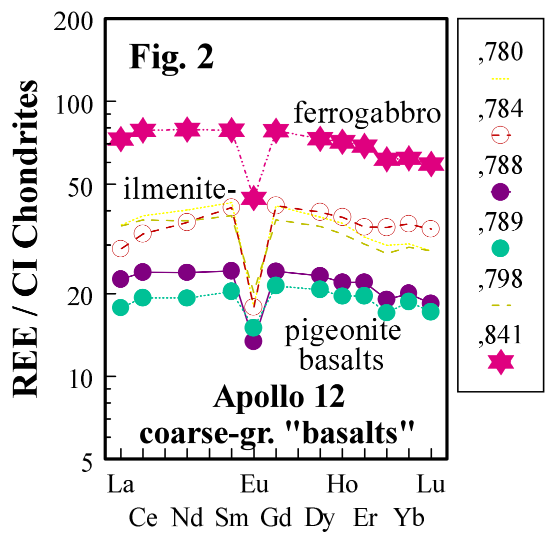
*Rock: GAB = gabbro; MR = mixed rock; PER = peridotite; IB = ilmenite basalt?; PB = pigeonite basalt?; FG = ferrogabbro.

gation from a thick basalt flow. The relatively evolved mafic mineral chemistry of this sample (olivine = Fo_{56-63}; [1]) indicates that, if this sample is from the lunar interior, it must have come from the differentiated upper mantle.

The three other igneous rocks among those with the lowest REE abundances (**,779**; **,786**; and **,825**) have similarly LREE-depleted patterns and modest negative Eu anomalies (Fig. 1; patterned circles). These three gabbros also have the lowest Be (0.16-0.29 ppm), Sc (31.6-39.3 ppm), Rb (0.14-0.28 ppm), Hf (1.17-1.38 ppm), U (0.023-0.045 ppm), Cu (9.1-11.3 ppm), and Zn (10.2-11.3 ppm), and highest Co (70.9-73.8 ppm) contents among these coarse-grained rocks (Table 1). The high mafic mineral content and/or low trapped liquid content of these samples is also indicated by the low abundances of Sr (62.4-75.4 ppm), Ba (16.6-21.1 ppm), Nb (1.6-2.3 ppm), Ta (0.089-0.15 ppm), Pb (0.14-0.40 ppm), Th (0.18-0.20 ppm), and Ti (7.083-11.93 mg), and high Cr (4383-7440 ppm) abundances (Table 1).



The sample with the highest REE abundances (**,841**) was classified as a **ferrogabbro** (Fig. 2; patterned star), due to the presence of fayalite (Fo_{2-3}), Cr- and V-poor and Ti-rich ilmenite, and evolved Fe-rich and Ca-poor rims on clinopyroxene and plagioclase, resp. [1]. Relative to all other rocks in this study, the evolved nature of this ferrogabbro is indicated by its enrichment in Ti (31.17 mg), Li (9.96 ppm), Be (1.26 ppm), Sc (83.9 ppm), V (264.2 ppm), Rb (2.90 ppm), Sr (220.8 ppm), Zr (240.1 ppm), Nb (15.8 ppm), Ba (187.4 ppm), Hf (8.30 ppm), Ta (1.17 ppm), Pb (1.76 ppm), Th (2.05 ppm), and U (0.61 ppm), Cu (36.5 ppm), Zn (35.6 ppm), and Ga (21.5 ppm) (Table 1). However, this sample is quite primitive relative to other ferrogabbros [6] and may represent a less-evolved component (possibly less trapped residual liquid?).



The remaining samples, although coarse-grained, have chemical compositions similar to mare basalt fragments from the Apollo 12 site [5,7]. In particular, sample **,784**, which was classified as an ilmenite gabbro [1], is similar in REE pattern (LREE-depletion), total REE (Fig. 2; open circle), Rb, Zr, Nb, Ta, Pb, Th, U, Ti, Cr, Co, Ni, Cu, to Apollo 12 ilmenite basalts. The main difference is in the lighter and volatile elements (Li, Be, Ga) and Sr, where this coarse-grained rock is depleted relative to the ilmenite basalts [5]. Similarly, samples **,788** and **,789** have REE patterns and elemental abundances similar to pigeonite basalts at Apollo 12 (Fig. 2; patterned circles). Thus, many of these remaining coarse-grained rocks could represent slowly cooled basalts, possibly from within thick flows.

CONCLUSIONS -- Great care must be taken in the classification of igneous fragments from soils. Many coarse-grained, presumably highlands-plutonic rocks are in fact slower cooled differentiates of mare basalts, possibly from within thick basaltic flows. However, we have identified one rare peridotite (possibly from the upper magma-ocean cumulate mantle), three gabbros, and one ferrogabbro among these ten 1-4 mm fragments.

REFERENCES: [1] Snyder, G.A. et al. (1996) **LPSC XVII**, 1239-1240; [2] Snyder et al. (1994) **LPSC XXV**, 1299-1300; [3] Snyder et al. (1995) **LPSC XXVI**, 1327-1328; [4] Snyder, G.A. et al. (1996) **LPSC XVII**, 1237-1238; [5] Snyder, G.A. et al. (1997) **LPSC XXVIII**, this volume; [6] Ryder, G. & Martinez, R.R. (1991) **PLPS 21**, 137-150; [7] Neal C.R. et al. (1994) **Meteoritics 29**, 334-348.